Chapter wise Power Point Slides for

The 8051 Microcontroller based Embedded Systems (First Edition)

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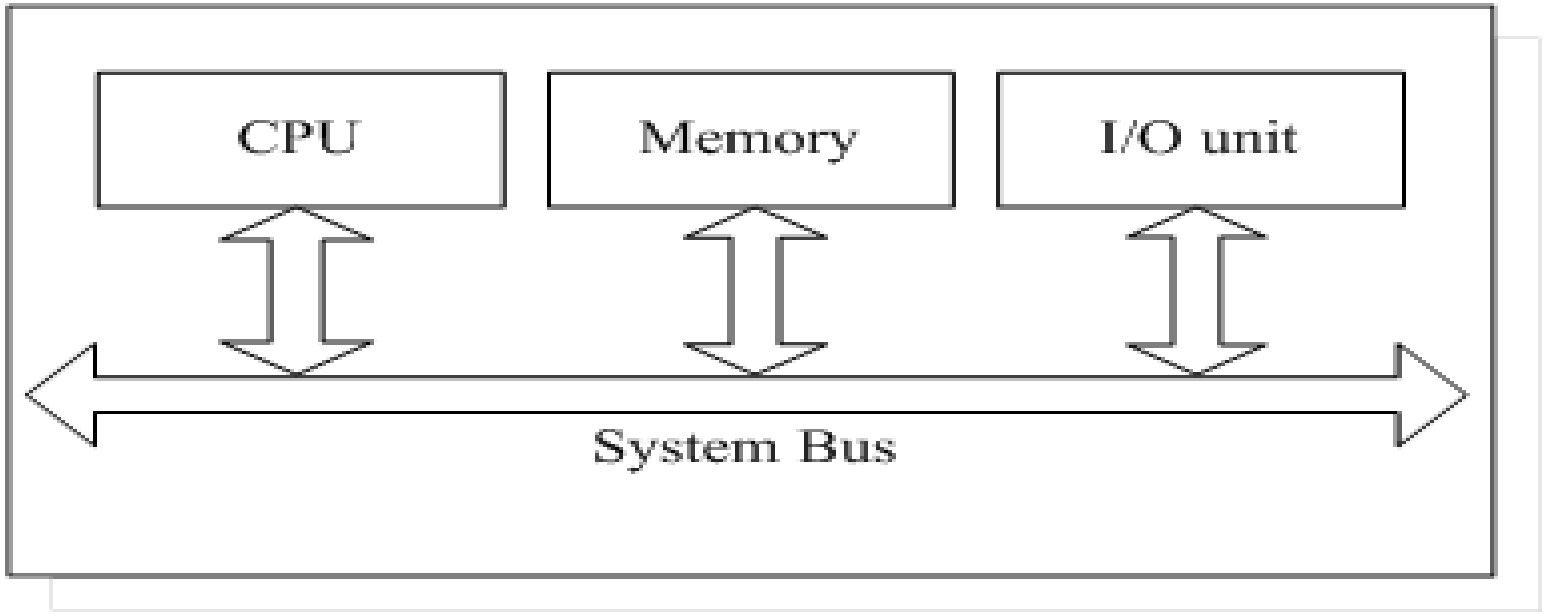
CHAPTER 1

INTRODUCTION TO MICROCONTROLLERS

CHAPTER OUTLINE

- COMPUTER SYSTEM
- MICROPROCESSOR, MICROCOMPUTER AND MICROCONTROLLER
- CLASSIFICATION OF MICROCONTROLLERS
- CHOOSING A MICROCONTROLLER
- APPLICATIONS OF MICROCONTROLLERS
- OVERVIEW OF THE 8051 FAMILY
- EMBEDDED SYSTEMS

COMPUTER SYSTEM



Basic components of a computer system.

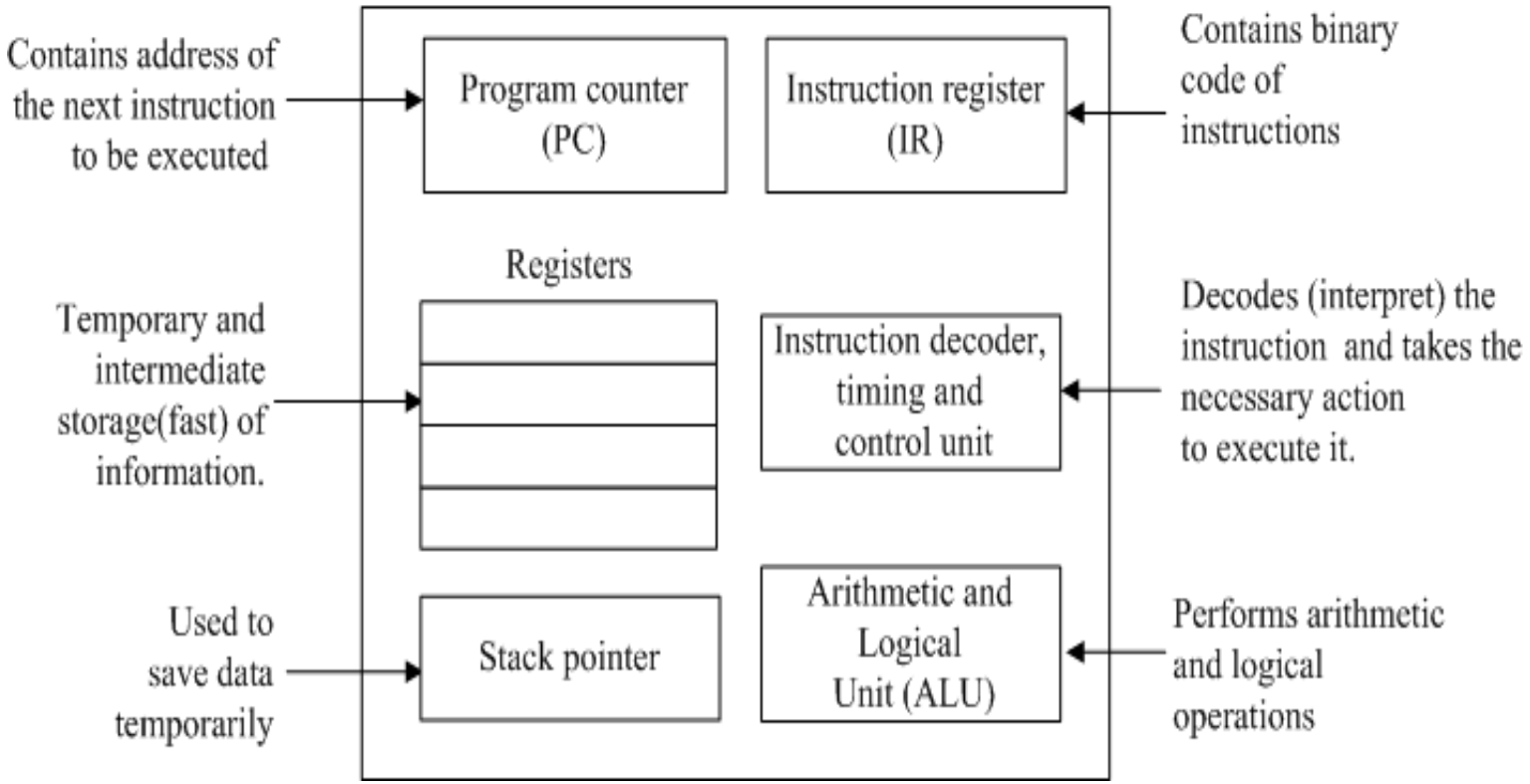
❖Central processing unit

The brain of a computer is the central processing unit. It consists of group of circuits that determine the operations that the computer can perform.

CPU components

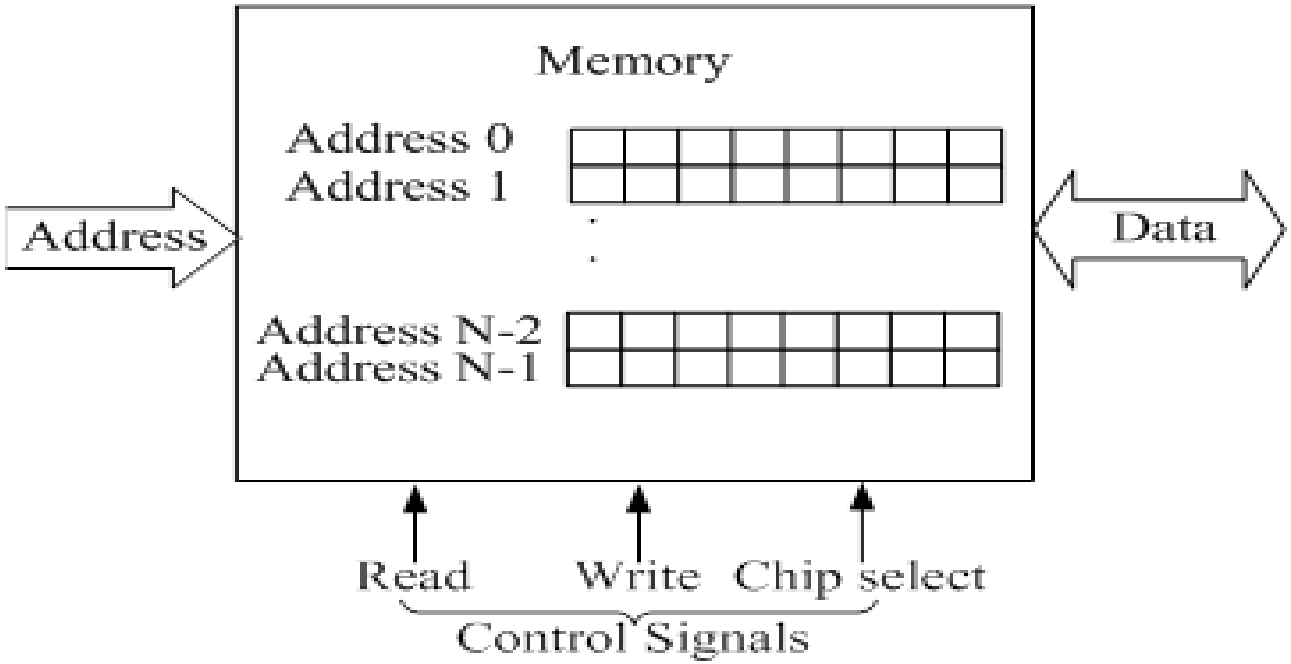
- **Arithmetic and Logic Unit (ALU)**
- **Registers**
- **Instruction register (IR)**
- **Program counter (PC)**
- **Stack pointer (SP)**
- **Instruction decoder and control unit**

General Block diagram of a CPU (Microprocessor)



Memory

The memory is used to store data and binary instructions. It is normally organized as several modules (chips), where each module contains several memory locations. Each location may contain part or all of the data or instruction. CPU reads (fetches) the instructions from the memory and performs operations (indicated by instructions) on data.



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❖ I/O unit

- **I/O port:**

  The hardware in a computer that allows information transfer between external world and computer is called I/O port.

- **I/O device (Peripherals):**

  The device that gives information to computer is called input device. For example, keyboard, mouse, joystick, microphone, A/D converters are all input devices.

- **I/O interfacing circuits:**

  The circuits that are used to interconnect (interface) I/O devices with a computer or I/O ports are called I/O interfacing circuits. For example, buffers, latches and voltage level converters are all interfacing circuits.

System bus

- **Address bus**

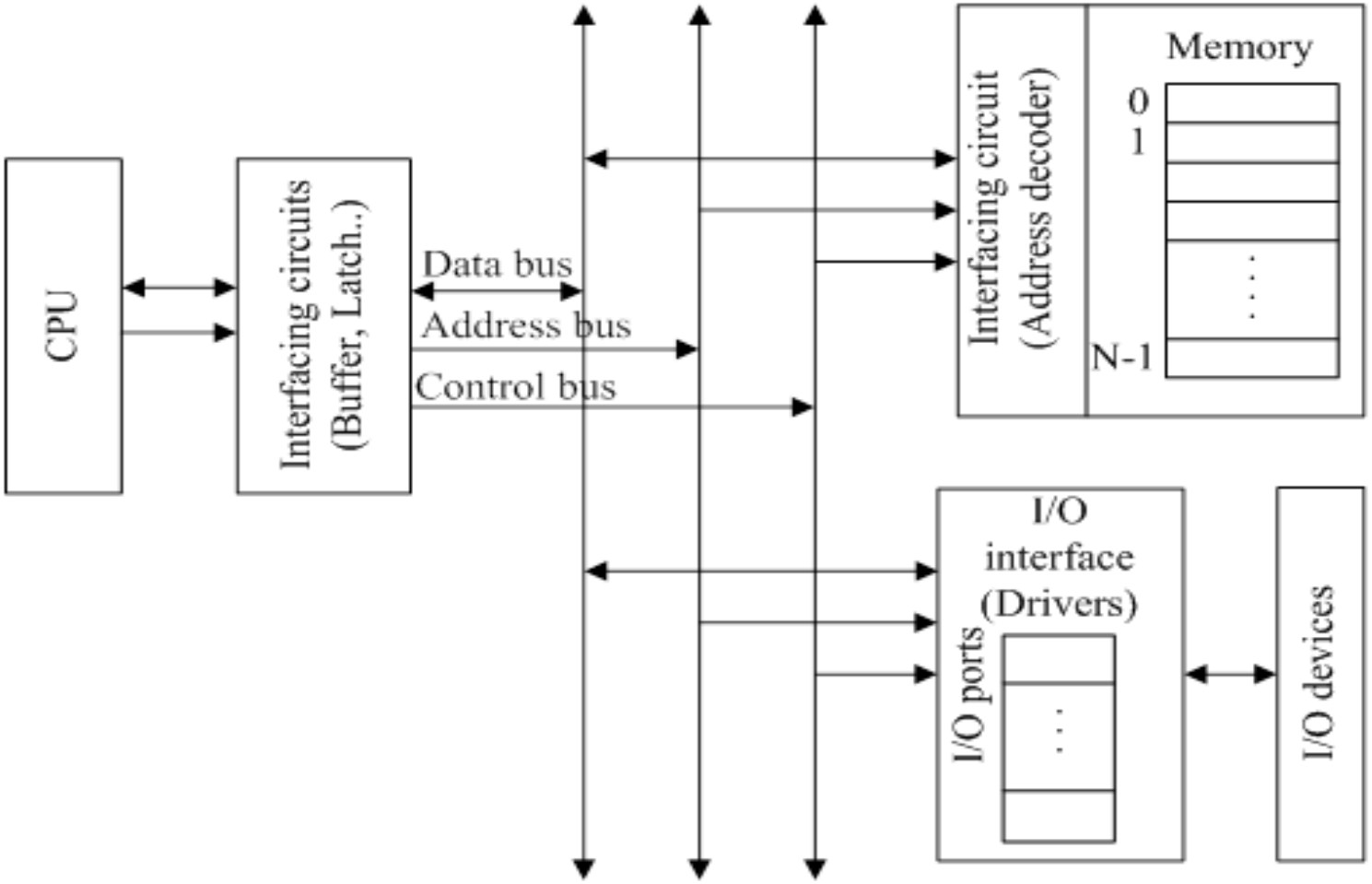
  It is group of wires used by CPU to identify specific memory location within a memory chip (also to identify specific memory chip out of many chips present in a computer system) and to identify I/O devices as well.

- **Data bus**

  It transfers data or instructions between CPU and memory or I/O devices. It is bidirectional because data can be transferred in both directions i.e. from CPU to memory (or output devices) or from memory or input devices to CPU.

- **Control bus**

  It is used to enable memory and I/O devices to perform read or write operations. It regulates all activities on the bus and specifies timing and direction of the data transfer. Read (RD), write (WR) and memory/ I/O (M/ I/O) are most common control signals.



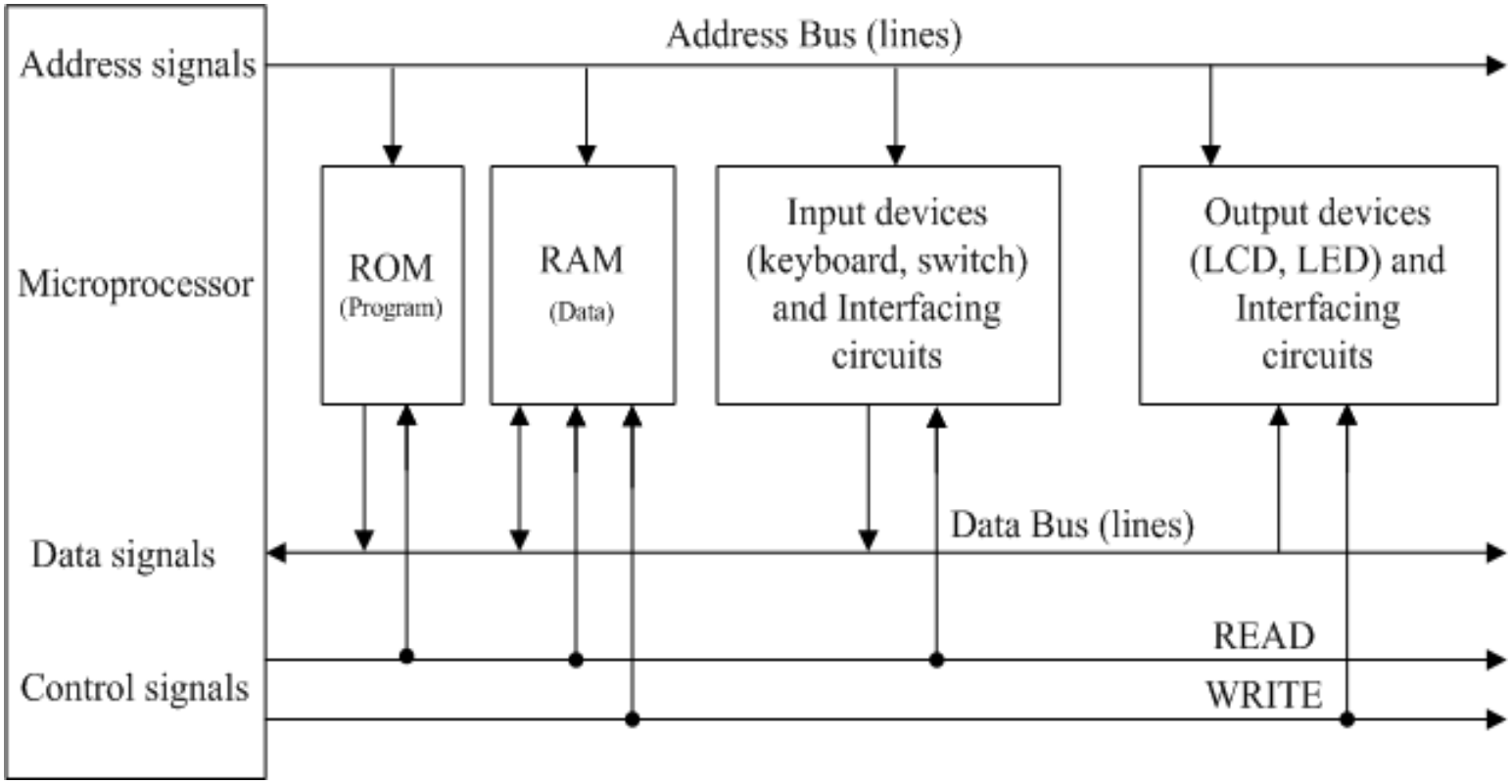
Computer block diagram with buses and interfacing circuits

MICROPROCESSOR, MICROCOMPUTER AND MICROCONTROLLER

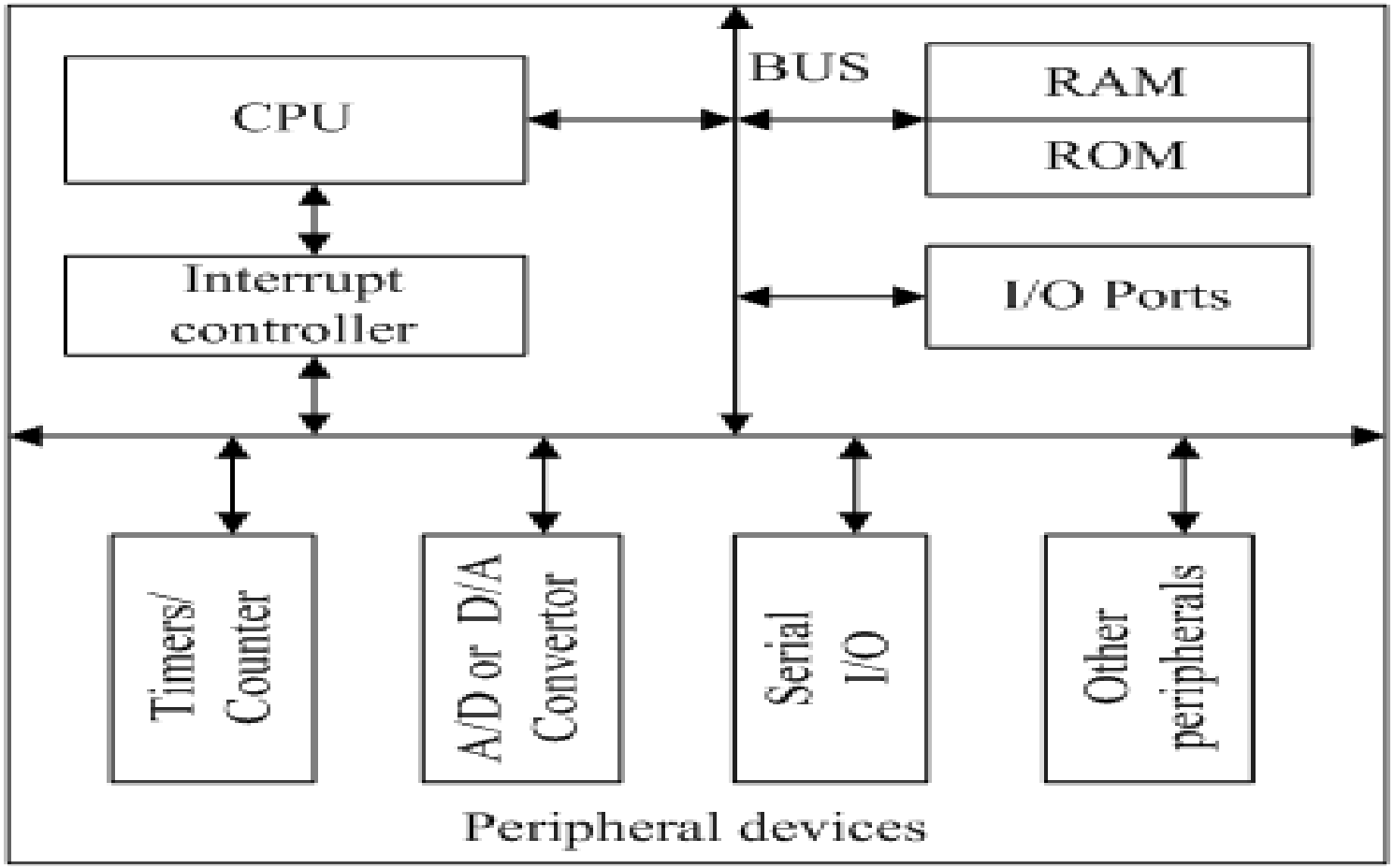
- **Microprocessor** is a central processing unit (CPU) built into a single semiconductor chip. The structure of microprocessor is same as CPU.

- **Microcomputer** is a small computer built using microprocessor as a central element. It includes all necessary components required for an application. The I/O devices and memory (types and amount) of a microcomputer are chosen as per the specific application.

- **Microcontroller** is an entire computer built into a single semiconductor chip. . It includes data and code memory, various on-chip peripherals like timers/counters, serial port, A/D converters, D/A converters etc, interface controllers, and general purpose I/O ports which allow it to directly interface to external environment.



Microcomputer system built around microprocessor



Block diagram of microcontroller

Comparison between microprocessor and microcontroller.

Microprocessor	Microcontroller
Microprocessor is complete functional CPU i.e. it contains ALU, registers, stack pointer, program counter, instruction decode and control unit and interrupt processing circuits.	Microcontroller is complete functional microcomputer i.e. it contains the circuitry of microprocessor and in addition it has built in memory (ROM, RAM), I/O circuits and peripherals necessary for an application.
Microprocessor instruction sets are data processing intensive, means powerful addressing modes and many instructions to move data between memory and CPU to handle large volumes of data.	Microcontrollers have instruction sets that are related to the control of inputs and outputs, means they have many bit handling instructions along with byte processing instructions.
Microprocessor based products are primarily designed to interact with humans and are more flexible to design	Microcontroller based products are primarily designed to interact with machines; once a system is designed they are less flexible.
Access times for external memory and I/O devices are more, resulting in a slower system.	Access times for on-chip memory and I/O devices are less, resulting in a faster system.
Microprocessor based systems require support devices and are usually bulkier, costly, less reliable and consume more power.	Microcontroller based systems require less external hardware, reducing PCB size and hence are compact, cheaper, more reliable and consume less power.
Software protection is not possible because of the requirement of external code memory.	Software protection is possible because of on-chip code memory.

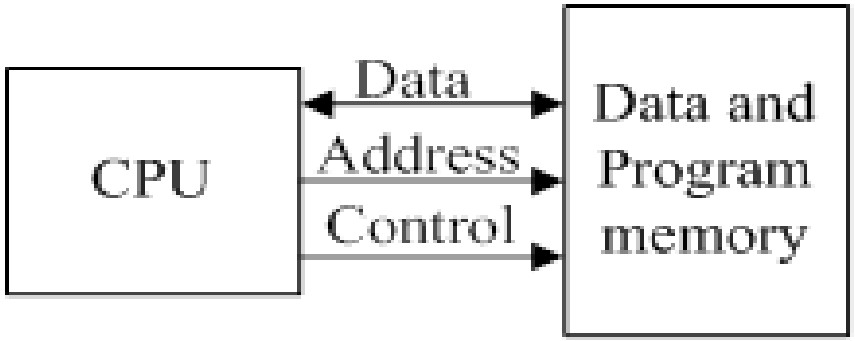
CLASSIFICATION OF MICROCONTROLLERS

- **Word length:**
  - 4 bit Microcontrollers
  - 8 bit Microcontrollers
  - 16 bit Microcontrollers
  - 32 bit Microcontrollers
  - 64 bit Microcontrollers
- **Memory Architecture:**
  - Von Neumann
  - Harvard Architectures
- **Core Architecture:**
  - Microcoded
  - Hardwired designs
- **Instruction set architectures:**
  - CISC
  - RISC

- **von Neumann Architecture:**

It has single memory storage to hold both program instructions and data i.e. common program and data space. The CPU can either read an instruction or data from the memory one at a time.

The advantage of Von Neumann architecture is simple design of microcontroller chip because only one memory is to be implemented which in turn reduces required hardware. The disadvantage is slower execution of a program.



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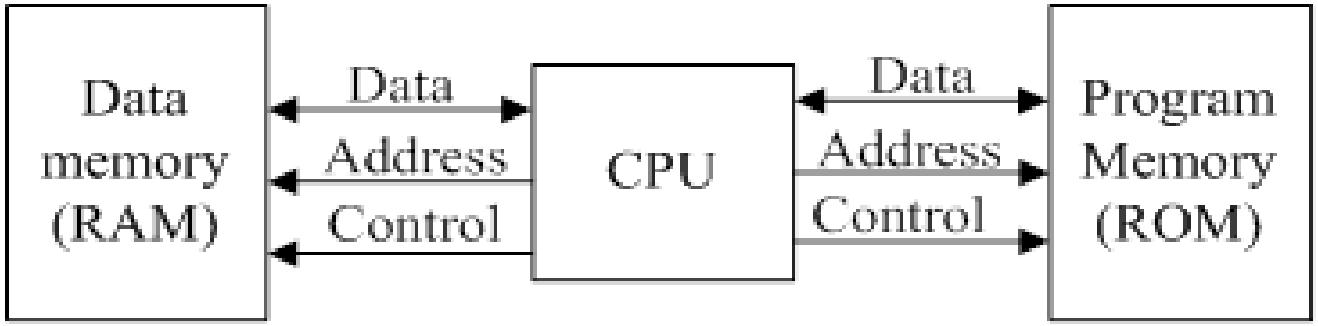
- **Harvard Architecture:**

It has physically separate memory storage to hold program instructions and data i.e. separate program and data space. Since it has separate buses to access program and data memory, it is possible to access program memory and data memory simultaneously. The advantage of a Harvard architecture microcontroller is that it is faster for a given circuit complexity because it offers greater amount of parallelism. The disadvantage is that it requires more hardware, because two sets of buses and memory blocks are required.



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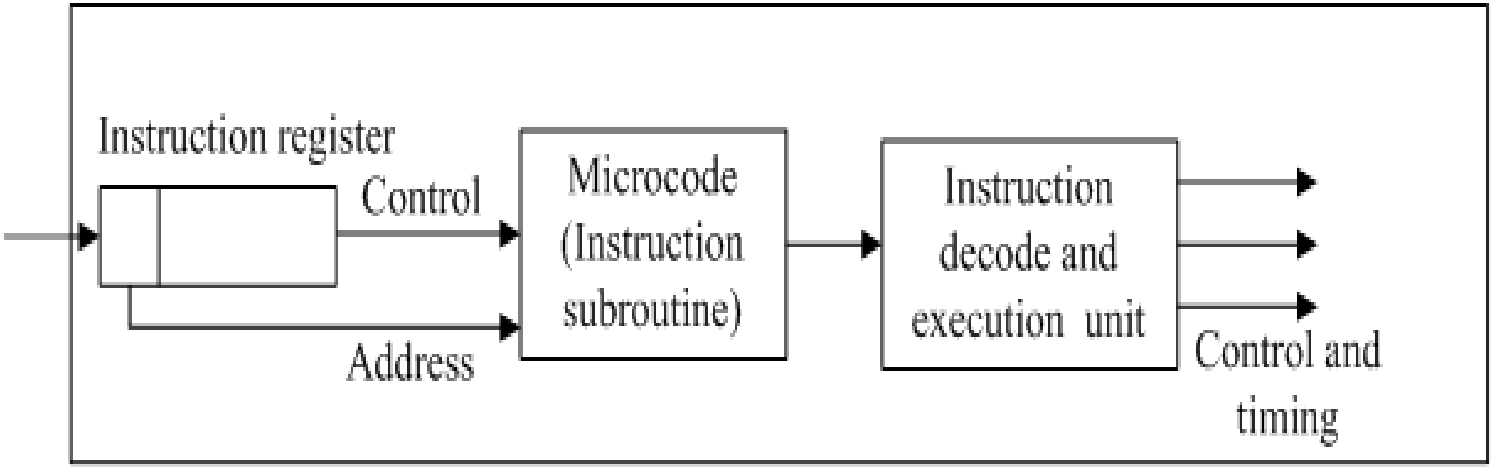
- **Microcoded design**

Microcode is a group of instructions used to implement the instructions of a microcontroller/ processor. It resides in a ROM or a programmable logic array (PLA) that is part of the microcontroller chip. The microinstruction is group of bits used to represent the sequence of control signals to fetch, decode and execute the instruction i.e. control signals (in a sequence) for every instruction are generated using memory.



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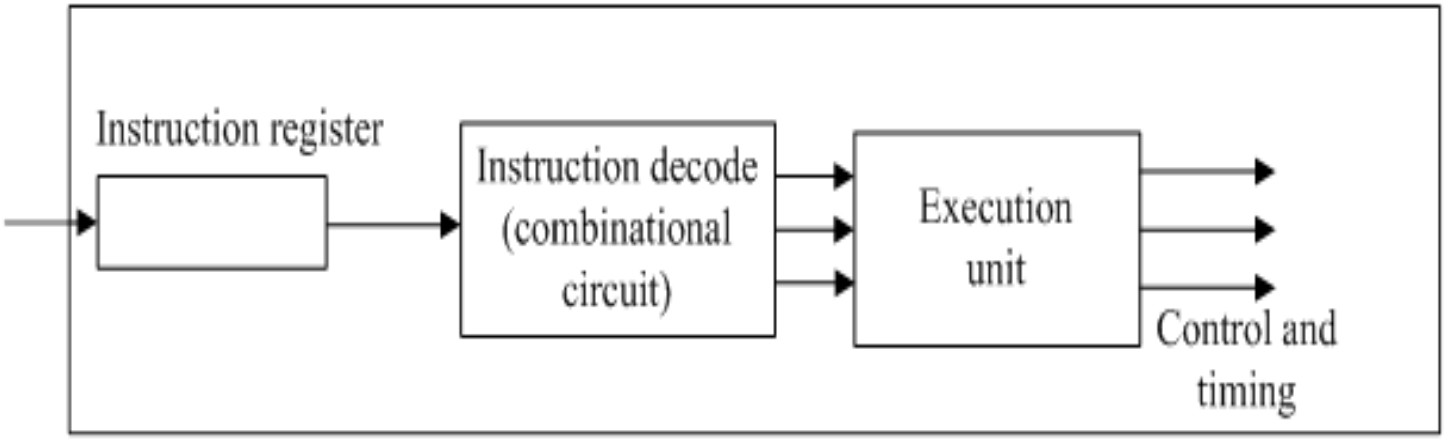
- **Hardwired design**

A hardwired microcontroller/processor uses the bit patterns of the instructions to select and activate specific circuits (may be unique to the each instruction) to execute the instructions. All control signals (or sequence of steps) required to fetch, decode and execute the instructions are generated and controlled by combinatorial logic and state machine circuitry.



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CISC: Complex Instruction Set Computer

- Complex hardware: complex as well as more addressing modes, variable instruction size.
- Many clock cycles to execute an instruction.
- High code density- small program size.
- Complex data types.

RISC: Reduced Instruction Set Computer

- Simple hardware: simple and less addressing modes, fix instruction size.
- Single clock cycle execution, uniform instruction format.
- Low code density- Larger program size.
- Few data types in hardware.
- Emphasis is on software: Compiler design is more complex.

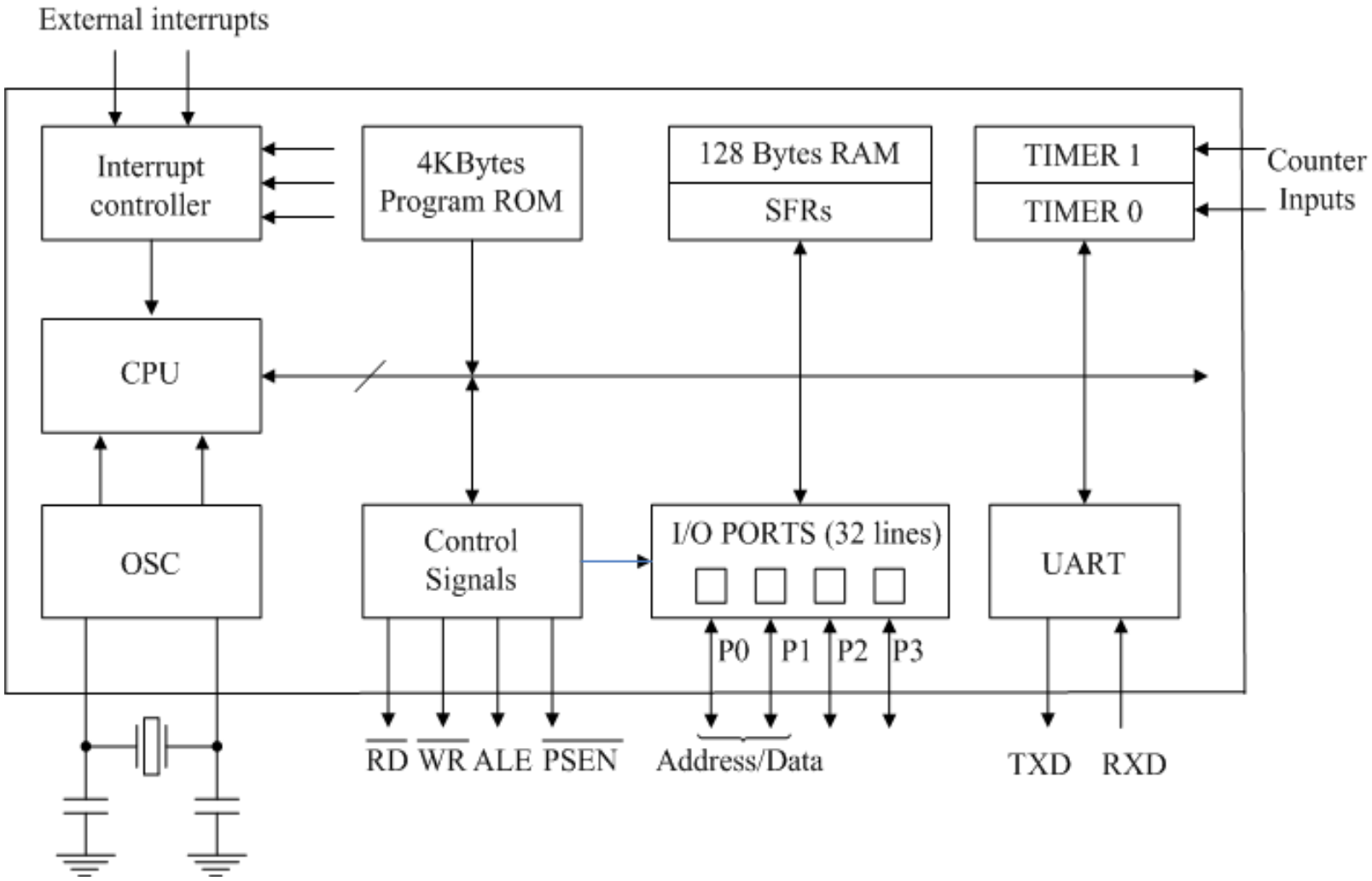
APPLICATIONS OF MICROCONTROLLERS

- Household appliances: Microwave oven, washing machine,
- Office and commercial appliances: Fax machine, photocopier
- Telecommunication: Telephones, phone answering machines, mobile phones
- Entertainment and gaming: Televisions, VCRs, music players
- Automotive industry: Fuel injection, ABS
- Industrial automation and manufacturing: Motor control systems, data acquisition and supervisory systems, industrial robots,
- Electronic measurement instruments: Digital multimeters, logic analyzers
- Biomedical systems: ECG recorder, blood cell analyzers
- Computer systems: Keyboard controller, CD drive or hard disk Military weapons, guidance and positioning systems.

OVERVIEW OF THE 8051 FAMILY

- **Features of the 8051 (MCS 51) family**

- The key features of 8051 microcontroller are:
- 8 bit CPU with Boolean processing capabilities.
- 4K bytes on-chip *program memory.
- 128 bytes on-chip data memory.
- 64 Kbytes each program and external data address space.
- 32 bidirectional I/O lines organized as four 8-bit I/O ports.
- serial port – Full duplex UART.
- 2 16-bit timers/counters.
- Two-level prioritized interrupt structure.
- Direct byte and bit addressability.
- Four register banks.
- Binary or decimal arithmetic support.
- Hardware multiply and divide operations.
- 12 clock cycles per machine cycle



The 8051 block diagram.

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Feature	8031	8051	8751	8032	8052	8752
Program memory	None ROM less	4K ROM	4K EPROM	None ROM less	8K ROM	8K EPROM
Data memory	128 Bytes	128 Bytes	128 RAM	256 Bytes	256 Bytes	256 Bytes
Timers/ Counters (16-bit)	2	2	2	3	3	3
I/O pins	32	32	32	32	32	32
Serial port	1	1	1	1	1	1
Interrupt sources (Reset not included)	5	5	5	6	6	6

Comparison of hardware resources of MCS 51 family.

EMBEDDED SYSTEMS

- They are designed to perform specific (or limited) tasks.
- They are tightly constrained with respect to power consumption, size, design, testing and manufacturing costs.
- These constraints are achieved by selecting microcontroller speed just sufficient to satisfy computational needs, limited memory, and limited peripheral resources to achieve design goal.
- They guarantee the response to events and completion of tasks within specified time. This is more popularly known as real time operation.

CHAPTER 2

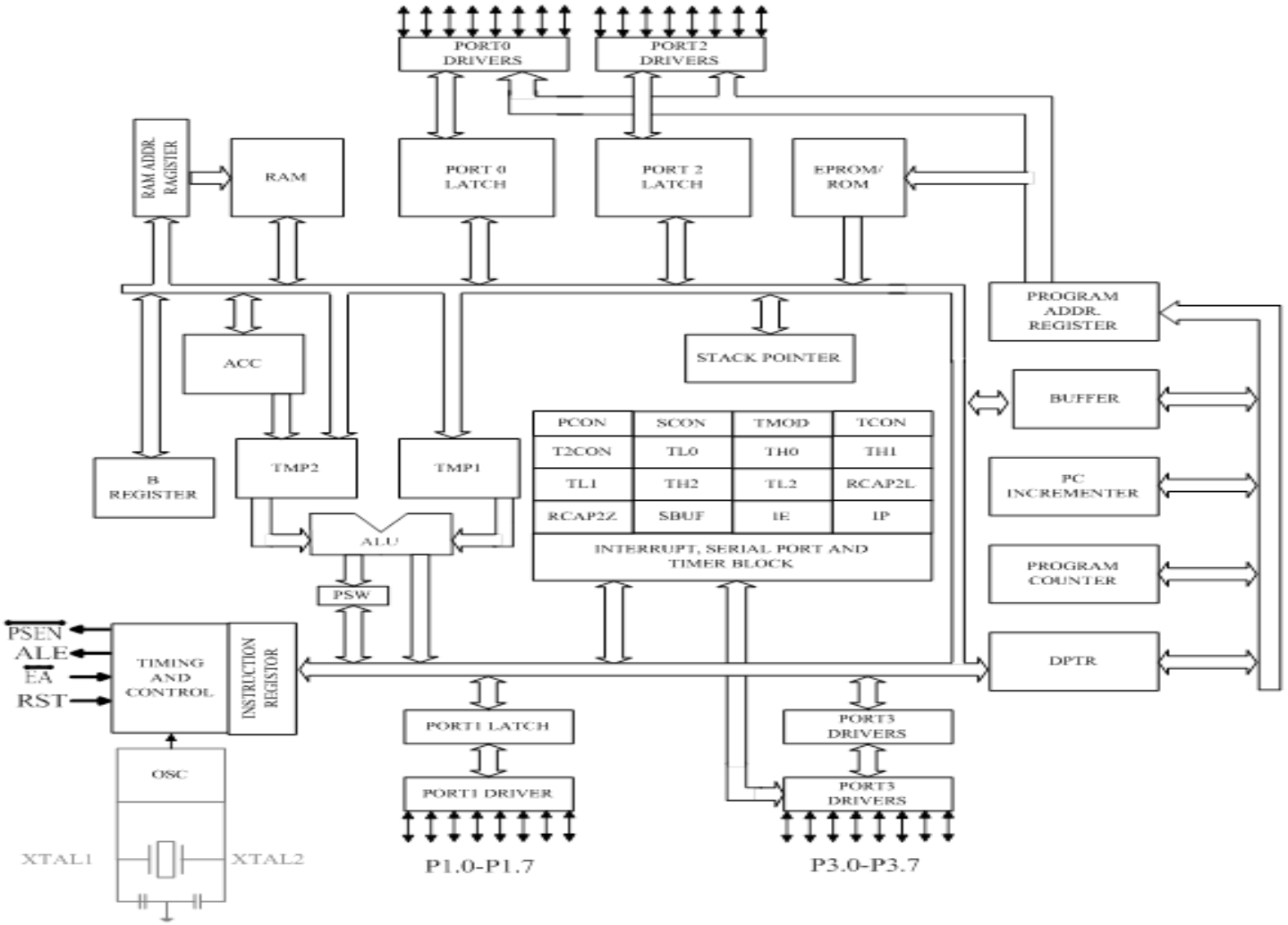
PROGRAMMING MODEL AND ARCHITECTURE OF THE 8051

CHAPTER OUTLINE

- THE 8051 ARCHITECTURE
- PROGRAMMING MODEL OF THE 8051
- ON-CHIP MEMORY ORGANIZATION
- EXTERNAL MEMORY ORGANIZATION

❖ THE 8051 ARCHITECTURE

- ALU
- Memory
- Peripherals
- Timing and control unit
- Oscillator



Block diagram of the 8051 microcontroller

- **ALU**

Arithmetic and logic unit performs all arithmetic (addition, subtraction, multiplication and division) and logical (AND, OR, NOT, EXCLUSIVE-OR and rotating) operations on 8 bit data i.e. the 8051 has 8 bit ALU. The ALU also updates information about the nature of the result in the flag register (PSW).

- **Memory**

The 8051 family has separate on-chip program and data memory. The program instructions are stored in a program memory. , 80C51 has 4Kbytes of on-chip ROM, whereas 80C52 has 8Kbyte (ROM) , 87C51 has 4Kbytes (EPROM) and 87C52 has 8Kbytes(EEPROM) of on-chip program memory. Data memory can be on-chip or off-chip. Internal data memory (RAM) in 80C51 is 128 bytes and in 80C52 is 256 bytes.

- **Peripherals**

The 8051 has two 16 bit timers (8052 has three timers) that are used for timing and counting applications. It has full duplex serial port (UART) to handle serial data transmission and reception.

- **Timing and control unit**

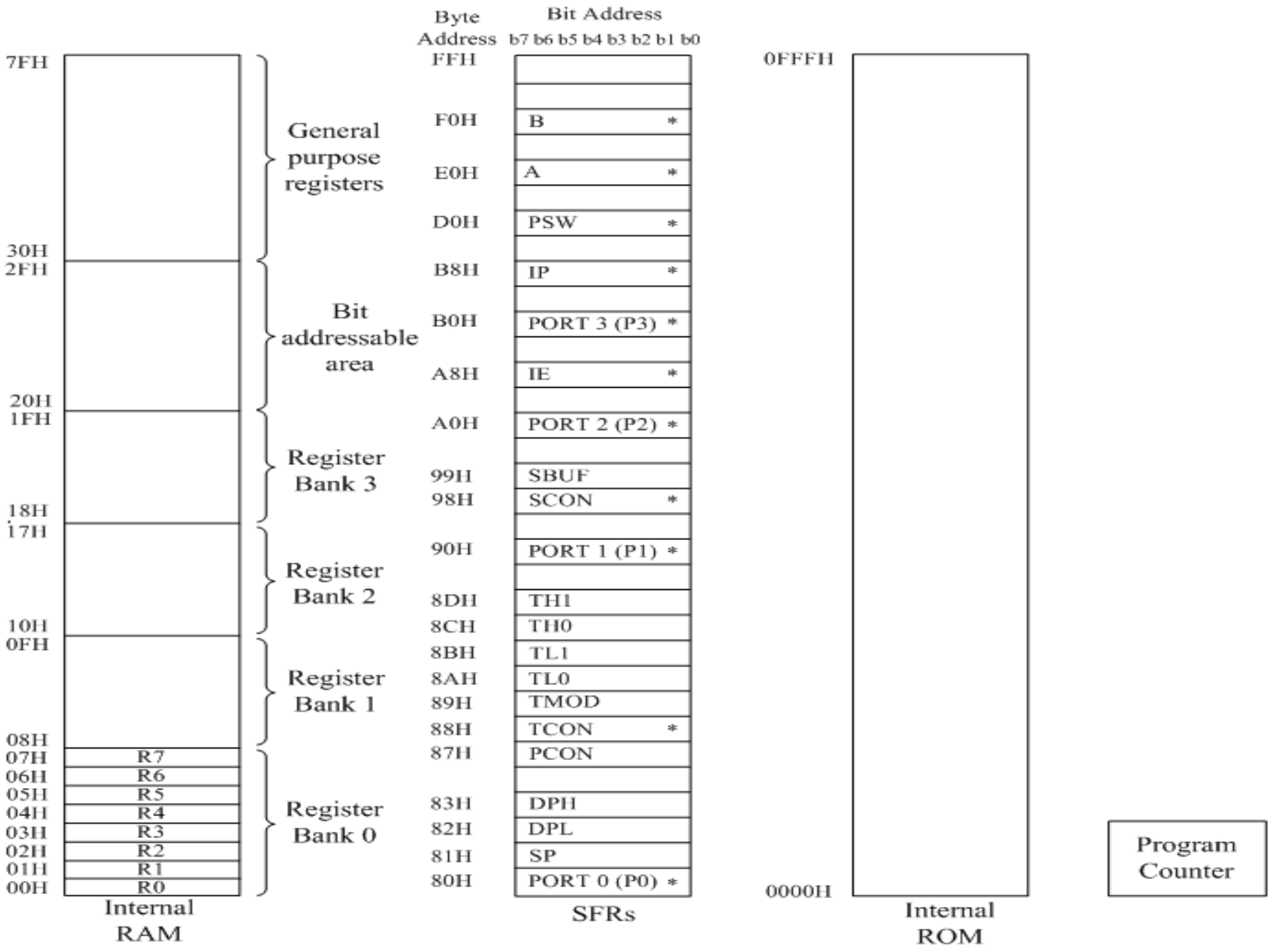
This unit generates all timing and control signals necessary for the execution of instructions and synchronizes all internal activities with the clock.

- **Oscillator**

The 8051 has an internal (on-chip) oscillator circuit which generates the clock pulses by which all internal operations are synchronized. Normally quartz crystal is used to make oscillator functional. Typically 12 MHz crystal is used.

❖ PROGRAMMING MODEL OF THE 8051

The programming model of 8051 contains 8 (or 16) bit registers and memory locations. Each register (or memory location) has an internal 1byte address with exception of program counter. Some registers are byte as well as bit addressable i.e. whole byte of data stored in a register can be accessed (read/write) at a time or individual bits can be accessed at a time.



Programming model of the 8051

❖ *ON-CHIP MEMORY ORGANIZATION*

- Special function registers (SFRs)
- Internal RAM
- Internal ROM

- ***Special function registers (SFRs):***
- Math registers: A and B.
- Status register: PSW (Program Status Word)
- Program counter: PC
- Pointer registers: DPTR (Data Pointer) and SP (Stack Pointer)
- Input output port latches: P0, P1, P2, and P3.
- Peripheral data registers: TL0, TH0, TL1, TH1, and SBUF.
- Peripheral control registers: IP, IE, TMOD, TCON, SCON, and PCON

- ***Internal RAM***

The 8051 has 128 bytes of internal RAM

- Register Banks: Bank 0, Bank 1, Bank 2 and Bank 3 (00H to 1FH)
- Bit Addressable RAM: Memory locations from addresses 20H to 2FH.
- General Purpose RAM: Memory locations from addresses 30H to 7FH.

- ***Internal ROM***
- The 8051 has 4Kbytes of internal ROM.
- It is used to store program instructions to be executed by the microcontroller. It may also be used to store permanent data like constants, passwords and lookup tables.

Special function registers (SFRs)

Accumulator: A

Accumulator is the most useful and versatile register because it is used in

i) all arithmetic operations like addition, subtraction, multiplication and division.

ii) Majority of logical operations like logical AND, OR, NOT, EX-OR and Rotate

iii) all data transfer between the 8051 and any external memory.

B

B is used along with A in multiplication operation to hold one of the operand (either multiplier or multiplicand) and to store higher order byte of the result. It is also used in division operation to hold divisor and to store remainder of the result.

PSW

Program status word is an 8 bit register. It is also referred as flag register or processor status word.

Program status word structure

PSW.7	PSW.6	PSW.5	PSW.4	PSW.3	PSW.2	PSW.1	PSW.0
CY	AC	F0	RS1	RS0	OV	--	P

Bit	Symbol	Flag name and description		
7	C (or CY)	Carry; Used in arithmetic, logic and Boolean operations		
6	AC	Auxiliary carry ; useful only for BCD arithmetic		
5	F0	Flag 0; general purpose user flag		
4	RS1	Register bank selection bit 1		
3	RS0	Register bank selection bit 0		
		RS1	RS0	
		0	0	Bank 0
		0	1	Bank 1
		1	0	Bank 2
		1	1	Bank 3
2	0V	Overflow; used in arithmetic operations		
1	--	Reserved; may be used as a general purpose flag		
0	P	Parity; set to 1 if A has odd number of ones, otherwise reset to 0		

Program counter: PC

Program counter (PC) is a 16-bit register. It always contains the memory address of the next instruction to be executed i.e. it points to the instruction that is to be executed next. As the CPU fetches the op-code (instruction byte) from the program memory, the PC is incremented automatically point to the next instruction.

Data Pointer: DPTR

DPTR is a 16 bit register. It is used to point to data byte in external data (RAM) or program (ROM) memory. It can be used as a single 16 bit register or can also be accessed as two separate 8 bit registers named DPL and DPH, where DPH means higher byte of the DPTR and DPL is lower byte of the DPTR.

Stack pointer: SP

Stack pointer always points to the top of the stack and used to access data from there. It is an 8 bit register. The data is stored on to the stack using PUSH and CALL instructions and retrieved using POP and RET instructions.

I/O port registers (latches): P0, P1, P2 and P3.

The 8051 has four 8 bit ports named as P0, P1 P2 and P3, each can be used as an input or output or both. All ports are byte as well as bit addressable.

Peripheral data registers: TL0, TH0, TL1, TH1, and SBUF.

TL0 (timer 0 lower byte) and TH0 (timer 0 higher byte) together represents a16 bit register for timer 0. They are also used as event counters. Similarly, TL1 and TH1 are registers for timer 1.

Peripheral control registers: IP, IE, TMOD, TCON, SCON, and PCON.

IP (interrupt priority) is used to assign priorities to different interrupt sources.

IE (interrupt enable) register is used to enable/disable interrupts.

TMOD (timer mode) is used to control behavior i.e. mode of operation of timers.

TCON (timer control) is used to start/stop timers.

SCON (serial port control) register is used to control the modes of operation of the serial port.

PCON (power mode control) register is used to select power saving modes of operations.

Internal RAM

The 8051 microcontroller has a total of 128 bytes of internal RAM. These bytes are assigned addresses 00H to 7FH. These 128 bytes are grouped into three different areas.

1. Register banks

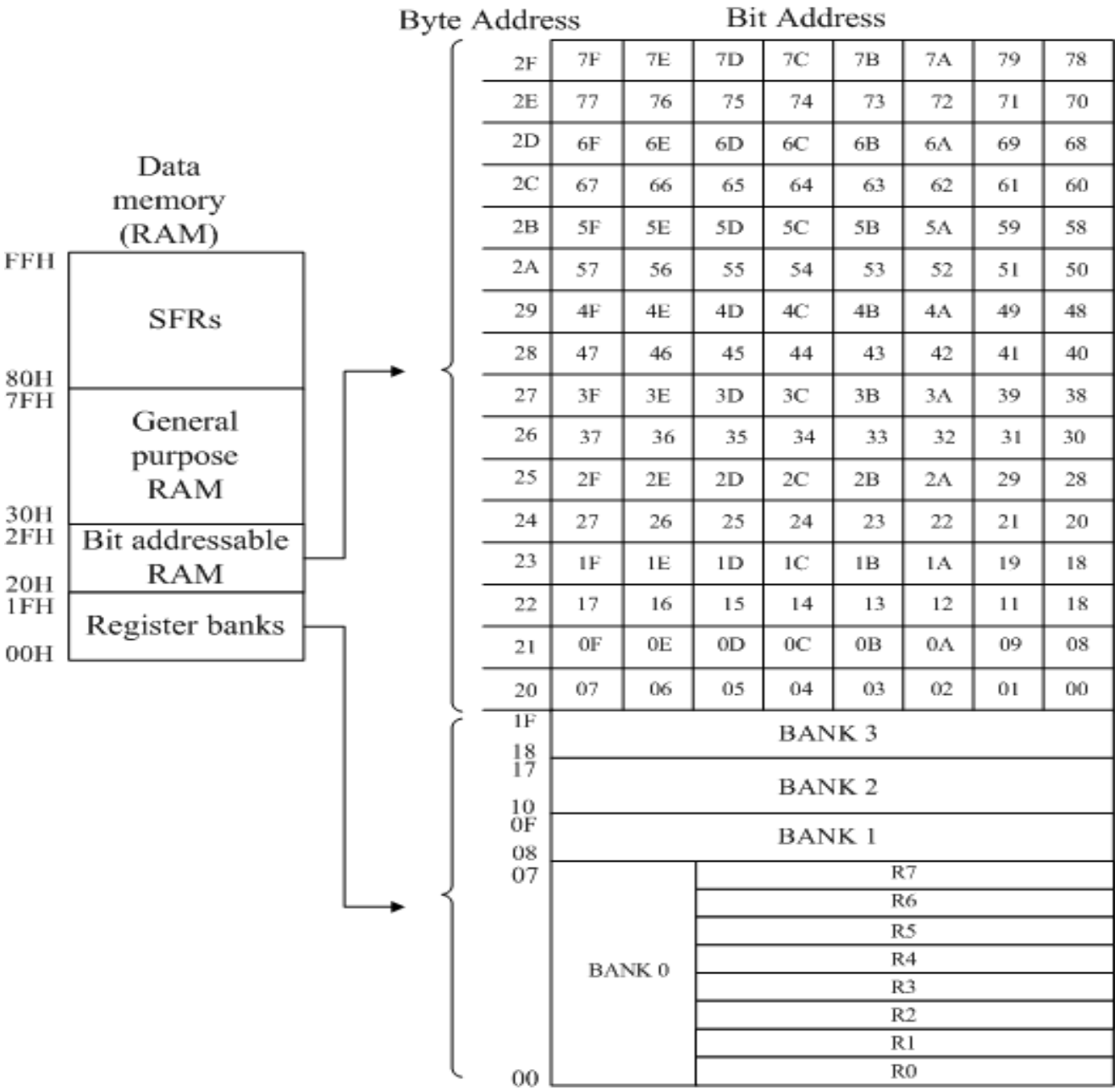
First 32 bytes from addresses 00H to 1FH are organized as four banks. Each bank is made up of eight registers named R0 to R7.

2. Bit addressable memory

The 8051 has a bit addressable area of 16 bytes from byte addresses 20H to 2FH in internal RAM, forming a total of 128 (16x8) addressable bits. An addressable bit can be accessed by its bit addresses from 00H to 7FH.

3. General Purpose RAM

Bytes from memory locations 30H to 7FH are used for general purpose data storage.



Internal RAM organization of the 8051

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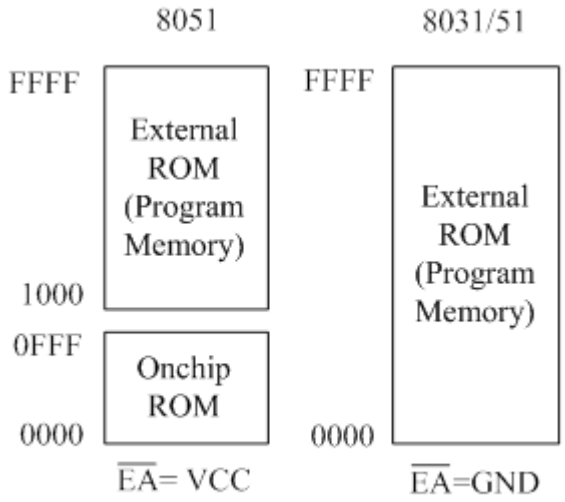
Internal ROM

The 8051 contains 4Kbytes of internal ROM (on-chip). It occupies address range from 0000H to 0FFFH. Since it is used to store program instructions (code), it is also called program memory or code memory.



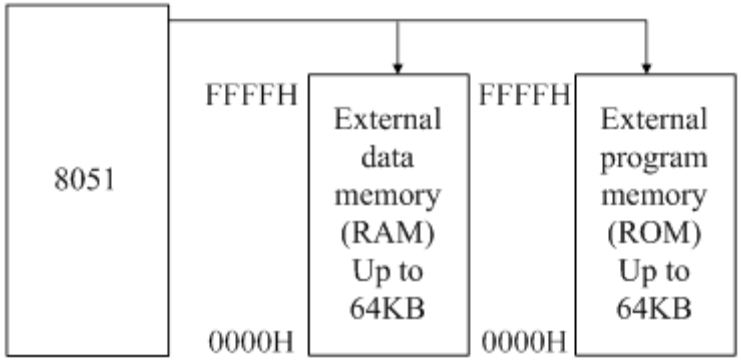
ROM organization of the 8051.

❖ EXTERNAL MEMORY ORGANIZATION

There are two parallel 64 Kilobytes address spaces

- one for the ROM(program memory).
- one for the RAM (data memory).

The data space is accessed using external data movement instructions (MOVX *A, source* or MOVX *destination, A)* and code space is accessed using external code movement instructions (MOVC A, *source)*.



External program and data memory space for the 8051